Water Quality Assessment and Modeling of Cuttack City

A THESIS SUBMITTED IN PARTIAL FULFILLMENT
OF THE REQUIREMENT FOR THE DEGREE OF

Bachelor of Technology in Civil Engineering

By

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Department of Civil Engineering
National Institute of Technology, Rourkela
2012

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Under supervision of
Prof. Somesh Jena

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National Institute of Technology
Rourkela
CERTIFICATE

This is to certify that the thesis entitled "Water quality assessment and modeling of Cuttack city" submitted by Lipi Mishra, Roll No. 108CE005 in partial fulfillment of the requirements for the award of Bachelor of Technology degree in Civil Engineering at the National Institute of Technology, Rourkela is an authentic work carried out by them under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University/Institute for the award of any Degree or Diploma.

Date: (Prof. SOMESH JENA)

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Abstract:

As Cuttack is located at the deltaic region of the Mahanadi River and its branch the Kathajodi, thus sufficient water resources are available.

Ground water exploitation through tube wells and dug wells are found to be more economic. In 1949, public health system organized the 1st pipe line water supply system from ground water source. Today its capacity is sufficient only for 35% of the urban population. Residents use water from shallow dug wells and tube wells located inside the city, of which a big portion is in close proximity of the main sewerage drain of the city and few septic tanks. Without treatment this water is used by the residents for years. Thus the study was carried out to assess the ground water quality throughout the city to see whether the components are within the standard permissible limit or not and thus to see which treatments are necessary to make suitable for the purpose of day to day use.

The rivers namely the Mahanadi and the Kathajodi and the Taladanda canal are the surface water source for the city. The rivers receive raw domestic sewage from the city. River Kathajodi receives raw sewage at two points, namely Mattagajpur and Khannagar. While the dangerous and infectious wastes produced by the SCB medical college and hospital and organic garbage from nearby markets are disposed in the Taladanda canal. The presence of few dairy farms and high population along the canal adds more pollution to the canal in the form of human and animal excreta.

Water samples were collected from these rivers and were tested in the laboratory for various water quality parameters. Previous year (2007-10) datas of various water quality parameters of the two rivers were obtained from the Orissa State Pollution Control Board office. Sreeter Phelp's equation was used for modeling of the water quality, few programs were compiled in MATLAB and were executed.

Keywords: nutrient, pollution, sewage, water.

1.1 Introduction:

Ground water plays a crucial role as a source of drinking water for millions rural and urban family. According to some estimates it accounts for nearly 80% of the rural domestic water needs, and 50% of the urban water needs in India. In India ground water is also intensively used for irrigation and industrial purposes. With the rising concentration of various inorganic, organic and biological contaminants in ground water there is rising concern on its effect on human health. A variety of industries contribute to concentrations of different pollutants in ground water. Ground water contamination is of particular concern in India. The chief source of drinking water in the country is ground water.

In many cities the water supply treated by the public health isn't sufficient for the whole urban population. The problem is acute in the ancient city of Cuttack. There are a substantial number of dug wells and tube wells as primary source of drinking water. A large number of studies have been carried out relating to ground water contamination by sewerage effluents which release NO_3^-, Cl^-, PO_4^{3-} & NH_4^+.

Very little literature is available on the quality of ground water in Cuttack city. The main sewer running through the city center has long been suspected of causing contamination of shallow wells located along the length of the drain.
Surface water resources have played an important role throughout history in the development of human civilization. About one third of the drinking water requirement of the world is obtained from surface sources like rivers, canals and lakes.
But, these sources serve as the best sinks for the discharge of domestic as well as industrial wastes. This unscientific disposal of wastes has caused immense problems not only to human beings but also to the aquatic environment worldwide. Studies on the major river ecosystems indicate that the major Indian rivers are grossly polluted. Thus studies need to be carried out in order to estimate the level of pollution in the surface water bodies.

1.2 Study Area:

Cuttack city ($20^0 26'02''$ to $20^0 29'55''$N, $85^0 48'20''$ to $85^0 56'30''$E) is surrounded by river Mahanadi and its tributary Kathajodi and the city is elongated in east-west direction. It enjoys a subtropical, monsoon climate with three distinct seasons (winter, summer and monsoon). The summer season continues from March to June and rainy season from June to October. The average annual rainfall is 154 cm with 74 rainy days. The depth of water table changes with the season as during pre monsoon it is 4 to 6 m below ground level and 0 to 2 m during post monsoon. The annual flow of the Mahanadi is 66 640×10^6 m^3, The flow of the river Kathajodi also reaches the peak during the rains. Besides the rivers the Taladanda canal originating at a barrage in the Mahanadi passes through the city in an east-west direction and serves as source of water for the city residents. The flow of the canal is fully controlled by the barrage but maximum flow occurs during rainy season.. The Mahanadi receives a part of the sewage near station 11, but the volume is much less than the amount of runoff.

2. Proposed Work With Objectives:

I was assigned the topic "water quality monitoring and modeling in Cuttack city". Data of various characteristics of the water of the rivers Mahanadi and Kathajodi over the past years were collected from the Orissa State Pollution Control Board. The four stations along Kathajodi where sampling is done are Mundali, Purighat, Khan Nagar, Gopalpur in order along the downstream. Similarly the four stations along the Mahanadi are Chahata Ghat, Gadagadia ghat, Jobra, Kanheipur. I was asked to design Streeter-Phelp's model on the two river waters with the help of the obtained data of DO and BOD. I compiled few programs based on the Streeter-Phelp's equation in MATLAB and executed them.

3. Literature On Studies Carried Out Earlier In India/Abroad:

From the journals I got to obtain the literature regarding the presence of standard ion concentrations. Incidence of fluoride above permissible levels of 1.5 ppm occur in 14 Indian states, namely Andhra Pradesh, Bihar, Gujarat, Haryana, Karnataka, Kerala, Madhya Pradesh, Maharashtra, Orissa, Punjab, Rajasthan, Tamil Nadu, Uttar Pradesh and West Bengal affecting a total of 69 districts, according to some estimates. Some other estimates find that 65 % of India's villages are exposed to fluoride risk.

Iron content above permissible level of 0.3 ppm is found in 23 districts from 4 states, namely, Bihar, Rajasthan, Tripura and West Bengal and coastal Orissa and parts of Agartala valley in Tripura.

High levels of arsenic above the permissible levels of 50 parts per billion (ppb) are found in the alluvial plains of Ganges covering six districts of West Bengal.

Use of chemical fertilizers in farms and disposal of human and animal waste on land result in leaching of nitrate, causing high nitrate concentration in groundwater. Nitrate concentration is above the permissible level of 45 ppm in 11 states, covering 95 districts and two blocks of Delhi. DDT, BHC, carbamate, Endosulfan, etc. are the most common pesticides used in India.

Pollution of groundwater due to industrial effluents and municipal waste in water bodies is another major concern in many cities and industrial clusters in India. A 1995 survey by Central Pollution Control Board identified 22 sites in 16 states of India as critical for groundwater pollution, the primary cause being industrial effluents. A recent survey carried out by Centre for Science and Environment from 8 places in Gujarat, Andhra Pradesh and Haryana reported traces of heavy metals such as lead, cadmium, zinc and mercury.

Mercury causes impairment of brain functions, neurological disorders, and retardation of growth in children, abortion and disruption of the endocrine system. Pesticides are toxic; they damage the liver and nervous system. Tumor formation in liver has also been reported.

High fluoride content is detected from symptoms on human beings as yellowing of teeth, damaged joints and bone deformities, which occur from long years of exposure to fluoride containing water.
Research has shown that long term exposure to chlorine leads to production of free radicals within the body. Free radicals are carcinogenic and it damages our cells. The risk of developing cancer is 93% higher in people exposed to chlorinated water. Chlorine can irritate and burn skin, eyes and throat.
Few drops of concentrated liquid ammonia may cause burns, inflammation and open sores if not washed away quickly. Breathing ammonia may cause difficulty breathing, excess fluid in the lungs and throat, and cardiac arrest.

Infants younger than 6 months of age are sensitive to nitrate poisoning, which may result in serious illness or death. The illness occurs when nitrate is converted to nitrite in a child's body. Nitrite reduces oxygen in the child's blood, causing shortness of breath and blueness of the skin, known as "blue baby syndrome."

Cuttack ground and river water quality assessment was carried out by J.Das and B.C. Acharya at the Mineralogy and Metallography Department, Regional Research Laboratory, Bhubaneswar (CSIR).

GROUND WATER:

Water samples were collected from approximately 60 points located throughout the city over 6 consecutive seasons and water quality analysis was done.
Samples were collected from the points in January. May and September of 1997-98, representing winter, summer and rainy season respectively.
Samples were collected from dug wells (depth of 8-12m) and tube wells (depth of 15-42m).
35 of the 60 points were selected in proximity of the main sewerage drain, they were grouped according to their distances from the drain as A,B,C,D,E. each group consisted of 7 sampling points located within a distance of 5,10,15,20 and 25m from the main sewerage line.
The rest of the 25 sampling points were selected randomly across the city and grouped as "F".
Samples were collected from 3 stations in the sewerage drain and were tested for water quality determination throughout the 6 consecutive seasons.
The maximum value of a sample for each parameter was compared with that of the sewage.

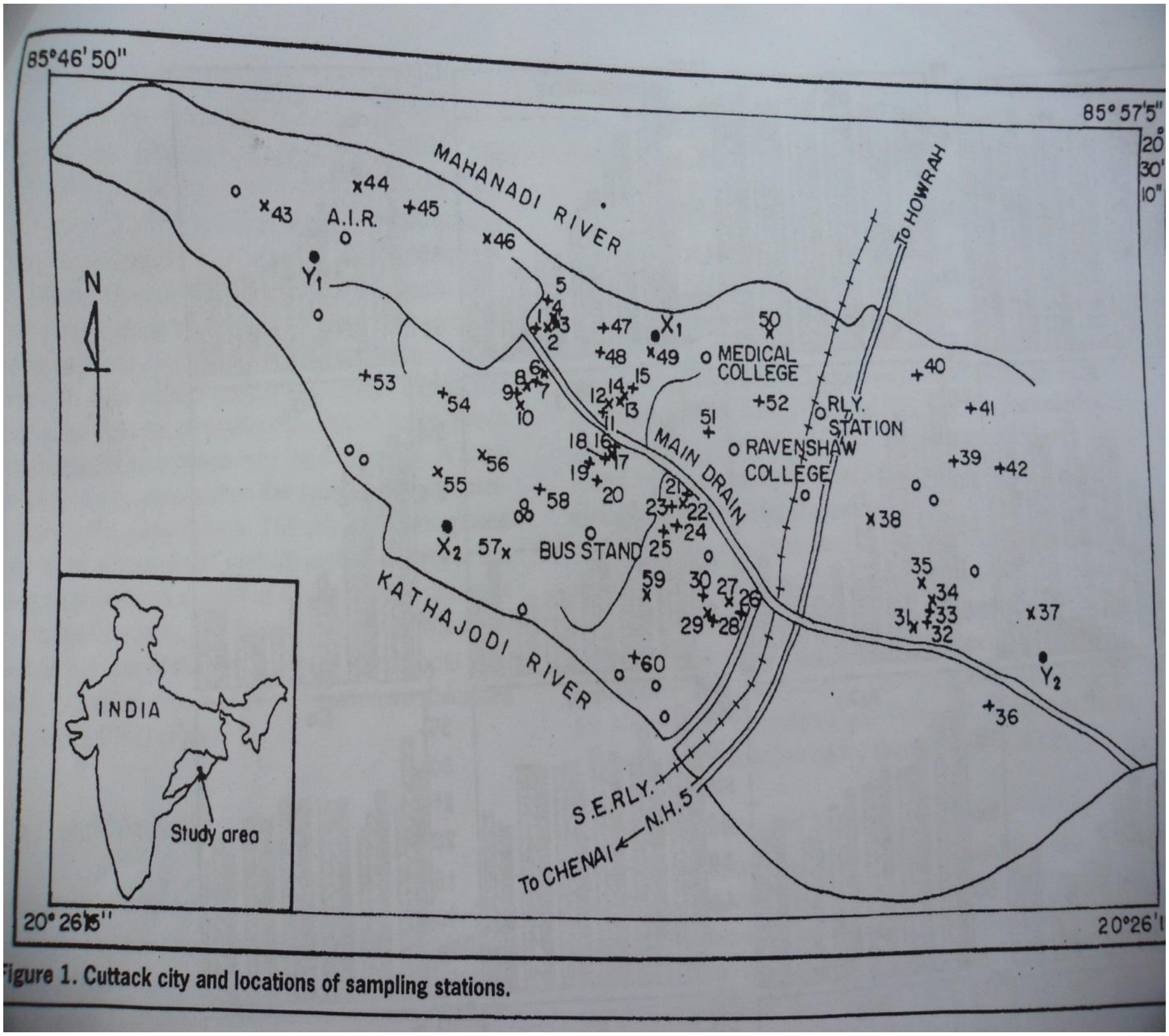
Standard methods were followed for the determinations of various physic-chemical properties such as temperature, total dissolved solids(TDS), electrical conductivity, fluoride, ammonium, nitrate, phosphate, sulphate, alkalinity, total hardness, calcium, magnesium, sodium, potassium and chloride.
From earlier studies carried out it was observed that raw sewage contained high concentration of Cl^-, NH_4^+, NO_3^- , SO_4^{2-} , PO_4^{3-} and EC as reported by several authors(Hegde et al. 1992, Behnke 1975, Tryon 1976). Various biological wastes e.g. dung, urine from diaries, septic tank effluents may be the reason for high concentration of these ions.

F^- concentration:

Stations A and B that were closer to the sewerage drain showed lower concentration of fluoride as compared to the other groups that were farther from the drain. The high concentration of fluoride in groundwater may be attributed to the geological deposits and the geochemistry of the place.
The fluoride concentration of the raw sewage samples were found to be similar to the samples from the group A and B, while it was less than that of the other ground water samples farther from it. So the lower concentration of fluoride of the samples from group A and B may be attributed to the mixing of the sewage with the groundwater at those locations. All the samples had fluoride concentration below the maximum permissible limit set by WHO.

NH_4^+, NO_3^- and PO_4^{3-} concentration:

The concentrations of NH_4^+, NO_3^- and PO_4^{3-} were found to be very high in the samples belonging to groups A, B and C. The values were very high for the raw sewage samples. It indicates degradation of groundwater quality is these areas.
All the stations which had the maximum concentration NH_4^+, NO_3^- and PO_4^{3-} belonged to group A and the variation of these concentrations with different seasons were similar to that of the samples of raw sewage, indicating the sewerage drain as the source of contamination of the ground water. The inverse relation of these concentrations with the distance of the sampling point from the drain further confirms this finding.



igure 1. Cuttack city and locations of sampling stations.

Fig-1: Map of the study area for ground water quality assessment

The samples from group A had concentration of NH_4^+, NO_3^- and PO_4^{3-} exceeding the maximum permissible limits set by WHO.

Therefore the high values of the concentrations of NH_4^+, NO_3^- and PO_4^{3-} in the ground water of the stations located nearer to the drain indicate leaching of these contaminants from sewerage drain into the groundwater.

According to estimations (WHO 1984) human excreta adds about 5kg of nitrogen per person per annum to the environment.

Comparison between maximum values of ground water and sewage water in three different seasons						
	Winter		Summer		Rainy	
	GW	SW	GW	SW	GW	SW
Temp(^{0}C)	26.9	26.8	30.4	31.5	28	28
pH	7.25	7.38	7.5	7.59	7.22	7.1
TDS(mg/L)	1202	1605	1247	1532	1040	1345
EC(µmho/cm)	1545	2116	1672	1987	1496	1715
F(mg/L)	0.82	0.57	0.88	0.6	0.75	0.52
NH_4^+(mg/L)	40	6.3	9.2	12.22	3.6	5.08
NO_3^-(mg/L)	97	186	92	142	93	160
PO_4^{3-}(mg/L)	5.2	11.82	3.8	8.25	2	3.64
SO_4^{2-}(mg/L)	88	145	80	105	70	140
Alk(mg/L)	218	225	192	237	180	212
TH(mg/L)	132	257	153	232	130	156
Ca^{2+}(mg/L)	35	58	42	67	32	50
Mg^{2+}(mg/L)	36	64	49	63	34	51
Na^+(mg/L)	422	461	486	492	400	418
K^+(mg/L)	43	101	58	94	43	72
Cl^-(mg/L)	226	315	272	320	200	207
GW= ground water, SW= sewage water						

In the aquatic environment NO_3^- reduces into NH_4^+ when D.O. is below 0.4ppm (Ghose and Sharma 1993). In anaerobic condition in summer reduction of NO_3^- to NH_4^+ may be the cause of highest concentration of NH_4^+ and lowest concentration of NO_3^- in the sewage during summer.

This anoxic condition also may be the reason behind low concentration of SO_4^{2-} during summer due to reduction by anaerobic bacteria.
Another reason behind low concentration of SO_4^{2-} may be the retention of the ion by soil components.

Total Dissolved Solids(TDS):

TDS value gradually decreased from group A to E.
The summer sample of group A gave the highest value of TDS of 1218mg/L. the TDS value of around 71% of the samples from group A exceeded the WHO set permissible limit.
The rainy season sample of group E gave the lowest value of TDS of 356mg/L.
From the inspection it was observed that the value of TDS of different stations varied inversely with the distance of those points from the drain, confirming that the drain is the main source of contamination of the ground water.
Same pattern was observed for electrical conductivity (EC).
Highest value of EC was observed for the summer sample of group A(1645µmho/cm)while the least value(467µmho/cm) was observed for group F.
As Cuttack receives around 85% of annual rainfall during rainy season, the pollutants get diluted and thus lower values are observed during rainy season.

Na^+ and Cl^- concentrations:

Highest values of concentration of Na^+ and Cl^- were observed in the samples of group A and B.
Highest concentration of Na^+ (466mg/L) and Cl^- (216mg/L) was obtained from the samples of group A during summer season while lowest concentration of Na^+ (75mg/L) and Cl^- (57mg/L) was that from group E during rainy season.
Maximum concentration of Na^+ and Cl^- were observed for group A samples.
Similar values were observed for the maximum concentration of Na^+ and Cl^- of the groundwater samples and sewage samples, in addition to it inverse relationship was observed between the values of the concentration of these contents and the distance of the stations from the sewerage drain, which confirmed the sewerage drain as the main source of contamination of the groundwater.

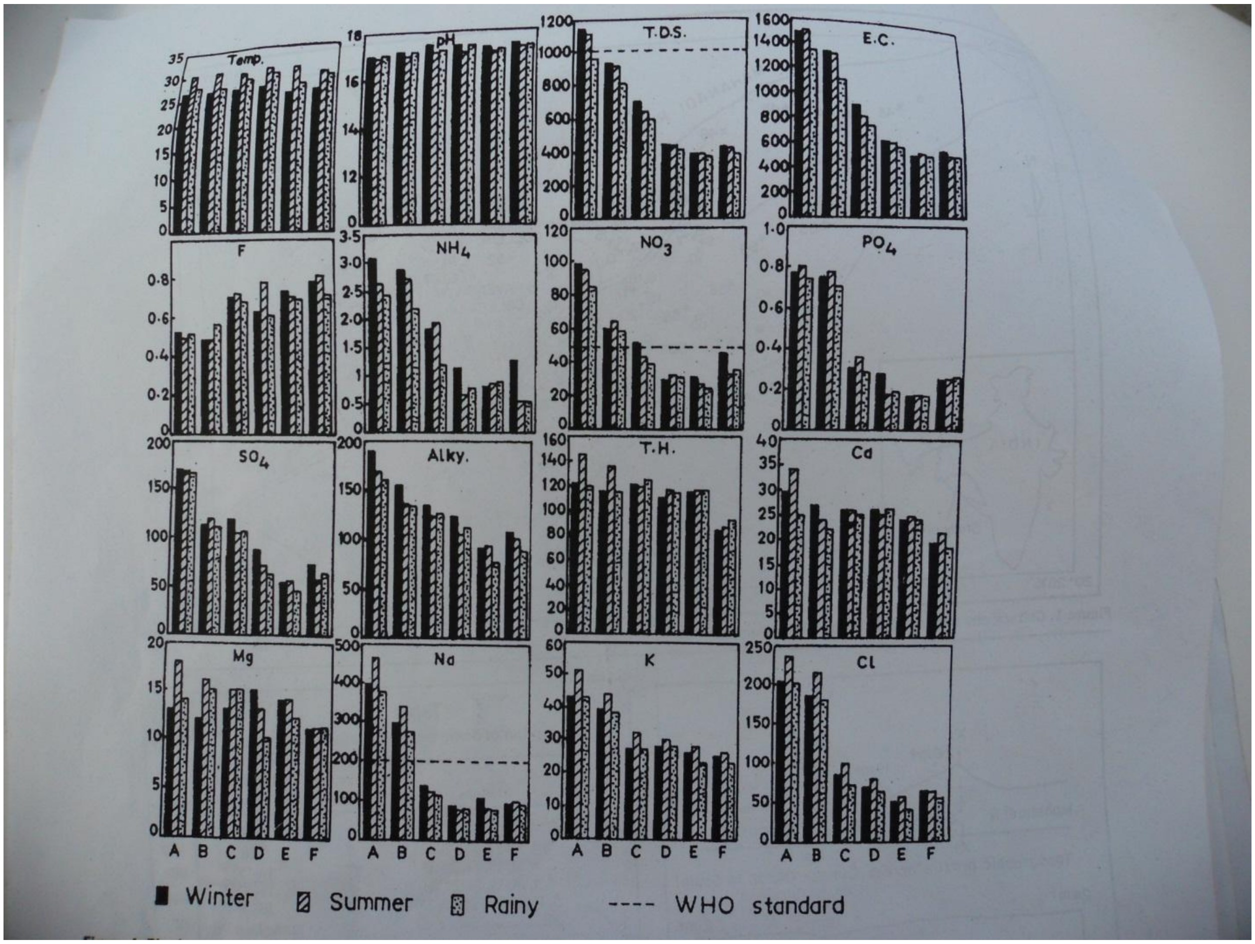


Fig 2: <u>Physic chemical characteristics of groundwater samples(avg) collected in different seasons</u>

A major source of Cl^- can be the septic tank effluents, as reported from earlier studies (Alhajjar et al. (1990) and Sekhar et al. (1994)).
Contribution of greater amount of Cl^- in the summer from the sewerage and dilution of the contaminant during rainy season accounts for the observed data of maximum ion concentration in the summer and minimum in the rainy season.

<u>pH</u>: According to earlier studies, sewage water has more pH value than normal drinking water as the algae present in the sewage accelerates the conversion of anionic compounds into hydroxyl form which results in increased pH value. The groundwater samples nearer to the sewage showed slightly higher pH than that of the stations farther away from the drain. This may be due to leaching of the sewage into the groundwater.

WHO Health org standards(1984) for drinking water and average percentage of each group exceeding the limit							
Indicators	**WHO (MPL)**	**% of stations above the limit**					
		A	**B**	**C**	**D**	**E**	**F**
pH	6.5-8.5	0	0	0	0	0	0
TDS(mg/L)	1000	71	14	14	0	0	8
F(mg/L)	1.5	0	0	0	0	0	0
NH_4^+ (mg/L)	1.5	86	86	14	14	0	12
NO_3^-(mg/L)	50	100	57	43	0	14	18
SO_4^{2-}(mg/L)	250	0	0	0	0	0	4
Na^+(mg/L)	200	100	86	14	0	0	4
Cl^-(mg/L)	250	43	29	14	0	0	12

Total hardness, Ca^{2+} and Mg^{2+} : Concentration decreased gradually from group A to E indicating higher concentration near the sewerage line. Also the maximum values of these parameters were comparable with the sewage. Thus it must be due to the mixing of the sewage water with the groundwater.

SURFACE WATER:

Water samples were collected from 17 stations located along the Mahanadi and the Kathajodi rivers and Taladanda canal over a period of 2years (1996-97) during different season, namely summer, rainy and winter season.

Some of the stations were located at the upstream and downstream of the sewage discharge points in the rivers to assess the extent to which river water is getting polluted due to discharge of untreated pollutants.

Sewage samples were collected from the sewerage drain at 3 stations.

Surface water samples were collected from 10cm below the water surface using a glass bottle and standard procedure was followed for the collection of the samples for water quality analysis.

- **<u>RAW SEWAGE:</u>**

The sewage samples were tested and presence of high concentration of various ions such as Cl^-, NH_4^+, NO_3^- , SO_4^{2-} , PO_4^{3-} and TDS was observed.
Heavy depletion of DO along with high values of BOD was observed throughout the study period. Presence of bio degradable matter and the utilization of the Dissolved oxygen by the microorganisms present might be the reason for it.
Concentration of Cl^-, NH_4^+ and BOD values registered the highest value during summer while that of NO_3^- and SO_4^{2-} were minimum.

- **<u>The surface water of the rivers and the canal</u>**

i. <u>pH and TDS</u>

The pH of the samples varied in the range from 7.38 to 7.81 which was well within the permissible limit set by WHO.
Value of TDS increased from rainy to winter then to summer season. Stations 1, 10 and 13, that were free from contaminated sewage showed comparatively lower values of TDS as compared to the stations 2 and 5 that receive the sewage discharge directly.

ii. <u>NH_4^+, NO_3^- and SO_4^{2-} :</u>

Ammonium concentration varied from 0.32 to 2.68mg/L. higher concentration was observed in the station from 2 to 9 in the Kathajodi river and stations 14 to 17 in the Taladanda canal during winter and summer seasons.
Around 59% of the sample collected in the summer and winter season exceeded the permissible limit of WHO while all the samples collected during rainy season were well below the maximum permissible limit.
The peak value of NH_4^+ was observed for the stations 2 and 5 of the Kathajodi river which is due to the rich sewage discharge at the 2 points Khannagar and Mattagajapur. The decrease in the concentration of the ion downstream can be due to the utilization of those ions by the phytoplankton and also due to the dilution effect.
The NO_3^- concentration varied from 14 to 126ppm. The samples collected during the rainy season at the upstream of the sewage discharge point of the Mahanadi and Kathajodi rivers showed maximum concentration of NO_3^- . The NO_3^- ion

usually generates from anthropogenic sources like farm lands, agricultural fields, domestic sewage and other waste effluents containing nitrogenous compound. The high concentration at the upstream of the sewage discharge point in the rainy season may be due to the runoff from a large catchment area.

Increase in concentration at the stations 2 and 5 along the Kathajodi river during summer and winter season was observed, it was due to the increased sewage effluent (Jain et al.1996)

iii. SO_4^{2-} concentration: It ranged from 21 to 105mg/L.

At stations 2 and 5 at sewage discharge points its value is high and it gradually decreased along the downstream stations. It's due to the influx of sewage at these points which decreases gradually along the downstream direction.

Higher content was also observed near the hospital waste discharge point at the station 14.

iv. **Cl^- concentration:**

It was found to vary from 22 to 145mg/L and none of the samples exceeded the maximum permissible limit by WHO.

But the Cl^- concentration was found to be much higher near the sewage disposal points as compared to the points upstream of it, it was due to the mixing of the domestic sewage at those points.

The stations at the rivers and canal were named from 1 to 17 as shown in the figure below:

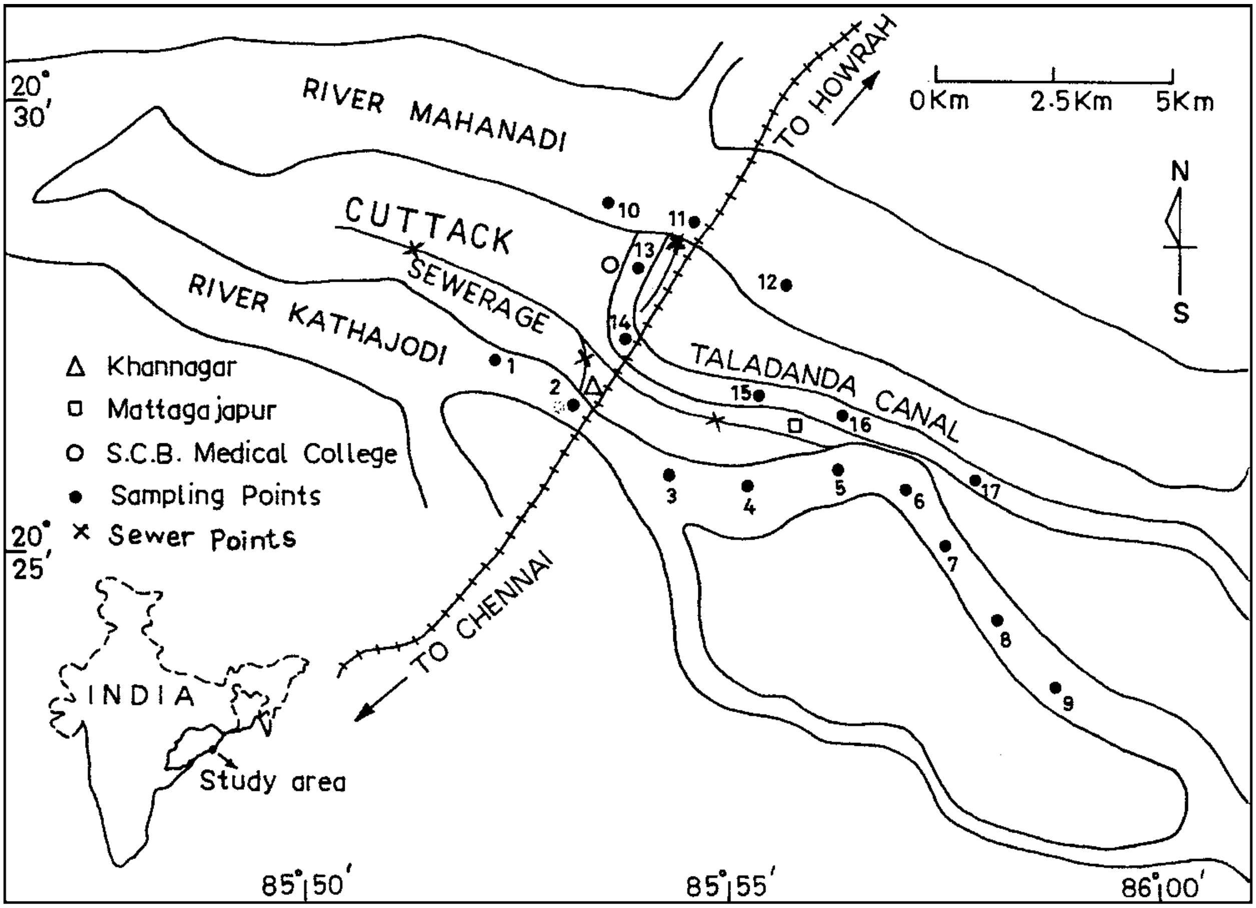
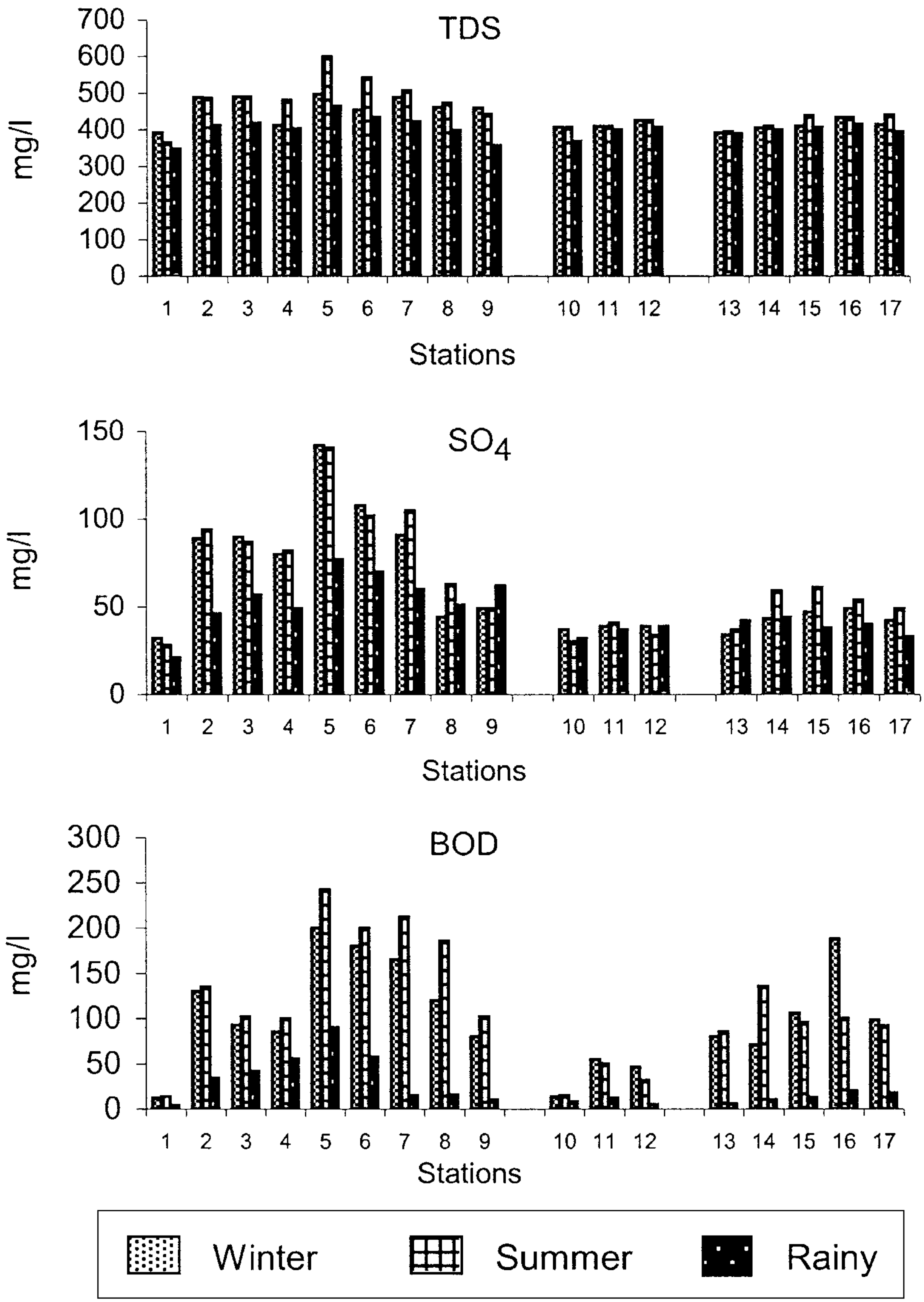
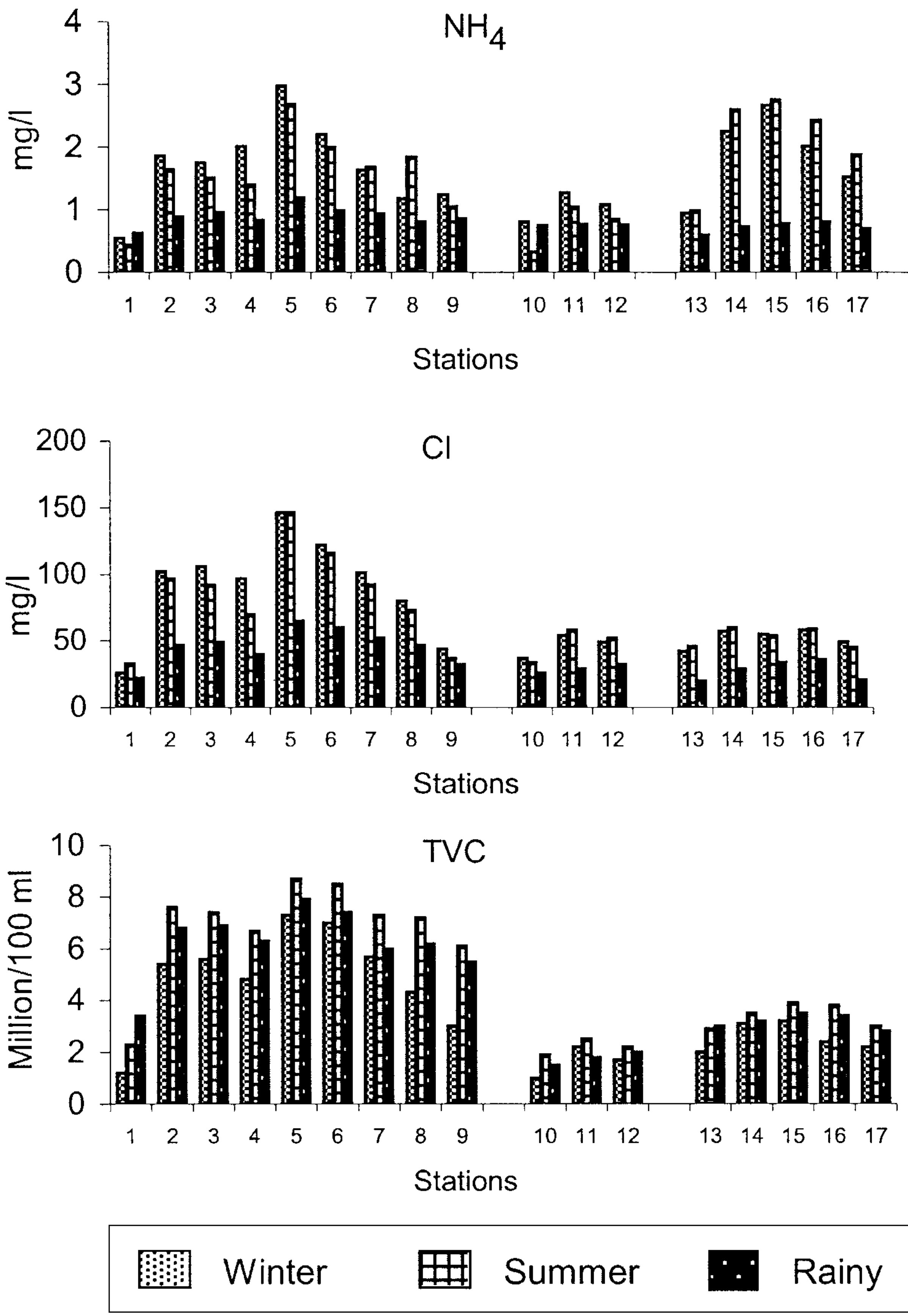


Fig-3: Map of the study area for surface water quality assessment


TDS
700
600
500
400
300
200
100
0
mg/l
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17
Stations
SO4
150
100
50
0
mg/l
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17
Stations
BOD
300
250
200
150
100
50
0
mg/l
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17
Stations
Winter
Summer
Rainy


NH4
mg/l
4
3
2
1
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17
Stations
Cl
mg/l
200
150
100
50
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17
Stations
TVC
Million/100 ml
10
8
6
4
2
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17
Stations
Winter
Summer
Rainy

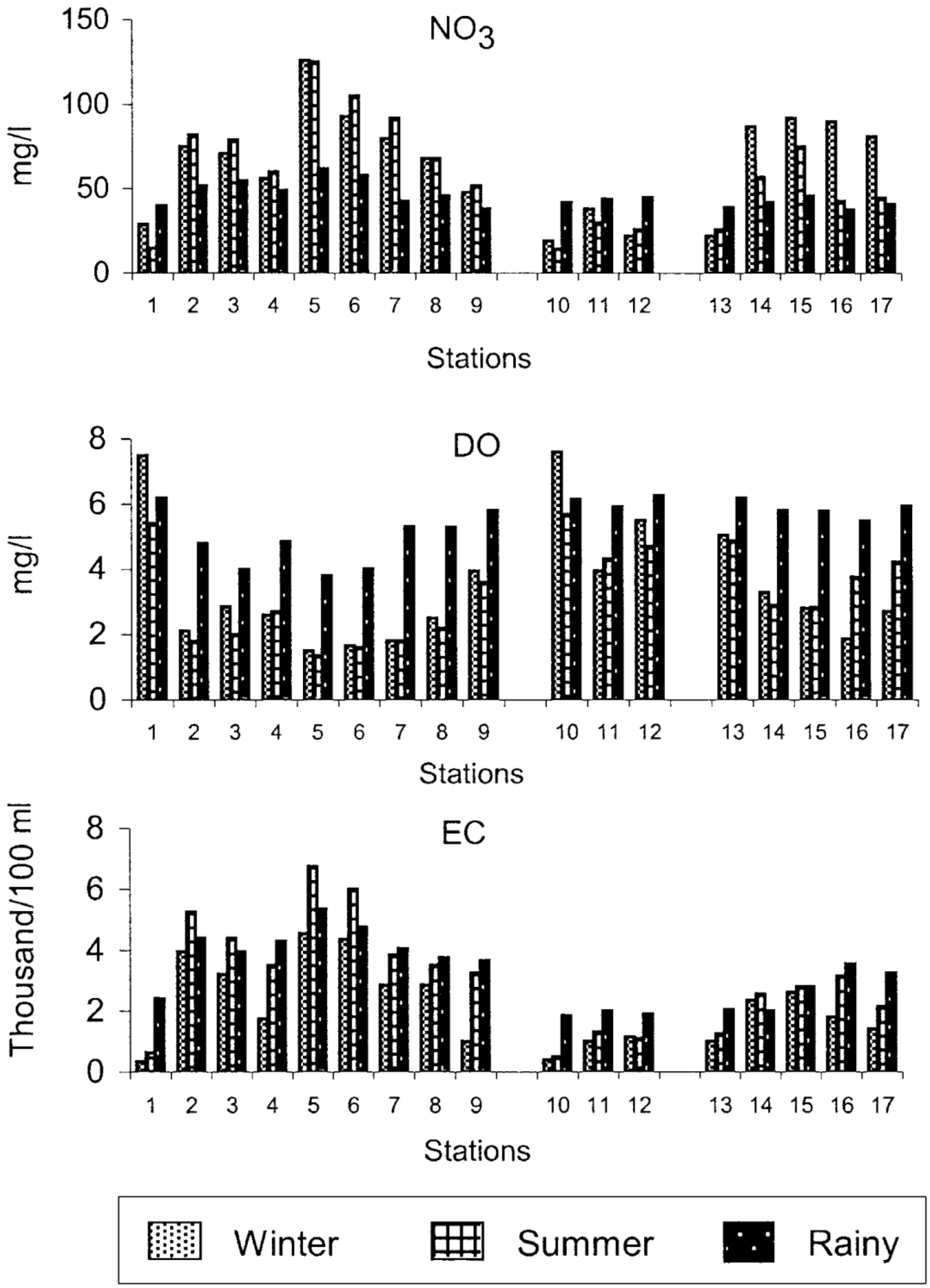


Fig 4: Physic chemical characteristics of surface water samples(avg) collected in different seasons

DO and BOD:

The DO concentration varied from 1.35 to 7.6mg/L.

Sudden depletion of the DO content was observed at the stations 2 and 5 of the Kathajodi river and station 11 of the Mahanadi river.

Very low DO was observed at the downstream points of the sewage disposal points in the rivers. It was due to addition of high organic contents leading to oxygen depletion.

The DO deficit persisted all along the 2 rivers and the canal indicating higher deoxygenation rate due to biological decomposition of organic matter than the reoxygenation rate from the atmosphere.

BOD value ranged from a minimum of 12 to a maximum of 242mg/L.

Sudden increase in BOD values were observed at the stations 2 and 5 and particularly during summer season. It was lower during rainy season.

High BOD values were observed at the downstream of the sewage discharge points in the Kathajodi river and the Taladanda canal, indicating the fact that they are largely polluted by organic matter.

In case of high load of organic matter discharged into surface water it gets oxidized downstream. But in the present case of Kathajodi river high BOD value persisted upto distance more than 7km, suggesting the fact that self purification system of the river has been inhibited for a long distance by heavy and unabated influx of domestic sewage.

Analysis:

From the analysis of the results it was seen that the stations like 1 and 10 that were upstream of the sewage and domestic waste mixing zone showed least concentration of all the ions including TDS. Other stations where the impact of sewage was insignificant showed similar results.

Moderately polluted zone: station 4,8,9 in Kathajodi(far away from the sewage mixing zone) and stations 14,15,16,17 along the Taladanda canal. These stations show relatively higher concentration of DO and lower concentration of the ions Cl^-, NH_4^+, NO_3^- , SO_4^{2-} , PO_4^{3-} as compared to the fully polluted zone. It indicated dilution of the pollutants while moving over some distance along the downstream.

Most polluted zone: stations 2 and 5 located just at the mixing zone of the domestic sewage showed very high concentration of all the ions, nutrients and high BOD value and very low concentration of dissolved oxygen. The stations located just after the discharge points, namely stations 3,6 and 7 also showed similar values of the concentrations.

Thus the main source of pollutants is the residential areas that produce both inorganic and organic wastes that discharge the untreated waste into river.

The Kathajodi was found to be most polluted followed by the Taladanda canal and then the Mahanadi.

Station 1 located upstream of the Kathajodi and sation 10 located upstream of the Mahanadi were found to be least polluted.

Contamination of the Kathajodi starts at the station 2 and continues till the last stretches of the study area.

The rivers are highly polluted in summer season followed by winter and rainy season. During summer lower water volume and accelerated growth of microbes in the high temperature results in depletion of DO thus making the water most polluted.

Situation in the Kathajodi can become alarming to the inhabitants in the study area if the sewage water isn't treated before discharging into the river.

4. Dissolved Oxygen & Biochemical oxygen demand:

The most important characteristic determining the quality of a river or stream is its dissolved oxygen. A stream is considered healthy if its dissolved oxygen DO exceeds 5 mg/L. Below 5 mg/L, most fish do not survive. Bacteria that feed on organic matter consume oxygen as part of their metabolism. The more organic matter is present, the more bacteria feed on it, and the greater the oxygen depletion. For this reason, the amount of organic matter is directly related to oxygen depletion, and it is useful to measure the quantity of organic matter not in terms of its own mass but in terms of the mass of oxygen it will have removed by the time it is completely decomposed by bacteria. This quantity is called the *Biochemical Oxygen Demand* and noted **BOD**.

Typical BOD values of sewage (in mg/L):-

• Untreated – low	100
• Untreated – average	250
• Untreated – high	400
• After primary treatment	80 to 120
• After primary and secondary treatment	30 or less

If the BOD of a waste is excessive and the DO value reaches zero, the absence of oxygen causes an anaerobic condition, in which the oxygen demanding bacteria die off and are replaced by an entirely different set of non-oxygen-demanding bacteria, called anaerobic bacteria. The by-product of their metabolism is methane (CH_4) and hydrogen sulfide (H_2S), both of which are gases that escape to the atmosphere which are ill-smelling .Such condition is to be avoided at all cost.

Under normal, aerobic conditions, organic matter decays at a rate proportional to its amount, that is, the decay rate of BOD is proportional to the BOD value.

Thus $d(BOD)/dt = -Kd*(BOD)$

Where, Kd is the decay constant of the organic matter.

Since by definition, BOD is the amount of oxygen that is potentially depleted, every milligram of BOD that is decayed entrains a loss of one milligram of dissolved oxygen.

Therefore, the accompanying decay of DO is:
$d(DO)/dt = -Kd\ (BOD)$

$$dL/dt = -K_d L$$

$$L_t = L_0 e^{-K_d t}$$

Where,
L_t - BOD in the water (usually mg/l)
Lo - initial BOD in the stream (usually mg/l)
K_d- is the rate coefficient of biochemical decomposition of organic matter (usually per day)
t - is the time, that is the time of travel in the river interpreted as $t=x/v$, where x is the distance downstream of the point of effluent discharge (t, usually days)

The decay coefficient depends on temperature.
The formula most often used is
$Kd(\text{at } T) = Kd(\text{at } 20^\circ C) * 1.047^{(T-20)}$
where T is here the temperature in degrees Celsius.

The accompanying table lists a few common values:

Waste type	***Kd at 20⁰C (per day)***
Raw domestic sewage	0.35–0.70
Treated domestic sewage	0.12–0.23
Polluted river water	0.12–0.23

The oxygen deficit of a polluted river-stream:

The oxygen deficit D at any time in a polluted river-stream is the difference between the actual DO content of water at that time and saturation DO content at the water temperature.

$$D_o = DO_{sat} - DO_0 \ \text{[mg/litre]}$$
$$DO_{sat} = 14.61996 - 0.4042T + 0.00842T^2 - 0.00009T^3$$

Where,
D_o - is the initial concentration of dissolved oxygen deficit in the river, downstream of the effluent discharge point (mg/l);
DO_0- is the initial concentration of dissolved oxygen in the river, downstream of the effluent discharge point (mg/l),
DO_{sat} - is the saturation oxygen concentration of water (mg/l);
T- is the water temperature (^{0}C).

Deoxygenation curve:

It represents the depletion of DO with time. In a polluted river-stream the DO content reduces due to decomposition of organic matter. The rate of deoxygenation depends on the amount of organic matter remaining to be oxidized at the given time as well as on the temperature of the reaction.

Reoxygenation curve:

In order to counter balance the consumption of DO due to deoxygenation atmosphere supplies oxygen to water. The rate of reoxygenation depends on:

- The depth of receiving water(rate more in shallow depth)
- The condition of body of water(rate is more in a running stream than in a quiescent pond)
- The temperature of the water.

Downstream of the sewage discharge point, the decay of BOD is accompanied by a consumption of DO, which in turn creates an increasing deficit of dissolved oxygen. But, as the oxygen deficit grows, so does the reaeration rate. At some point downstream, reaeration is capable of overcoming the loss due to BOD decomposition, which gradually slows down as there is increasingly less BOD remaining. The net result is a variation of dissolved oxygen downstream of the discharge that first decays and then recovers, with a minimum somewhere along the way. Plotting the DO value as a function of the downstream distance yields a so-called oxygen-sag curve.

i. Zone of degradation: Just below the point of discharge sewage into the river stream. Water becomes dark and turbid with formation of sludge deposits at bottom. DO is reduced to about 40% of saturation value. Reoxygenation is slower than deoxygenation. Conditions are unfavourable to the development of aquatic life.

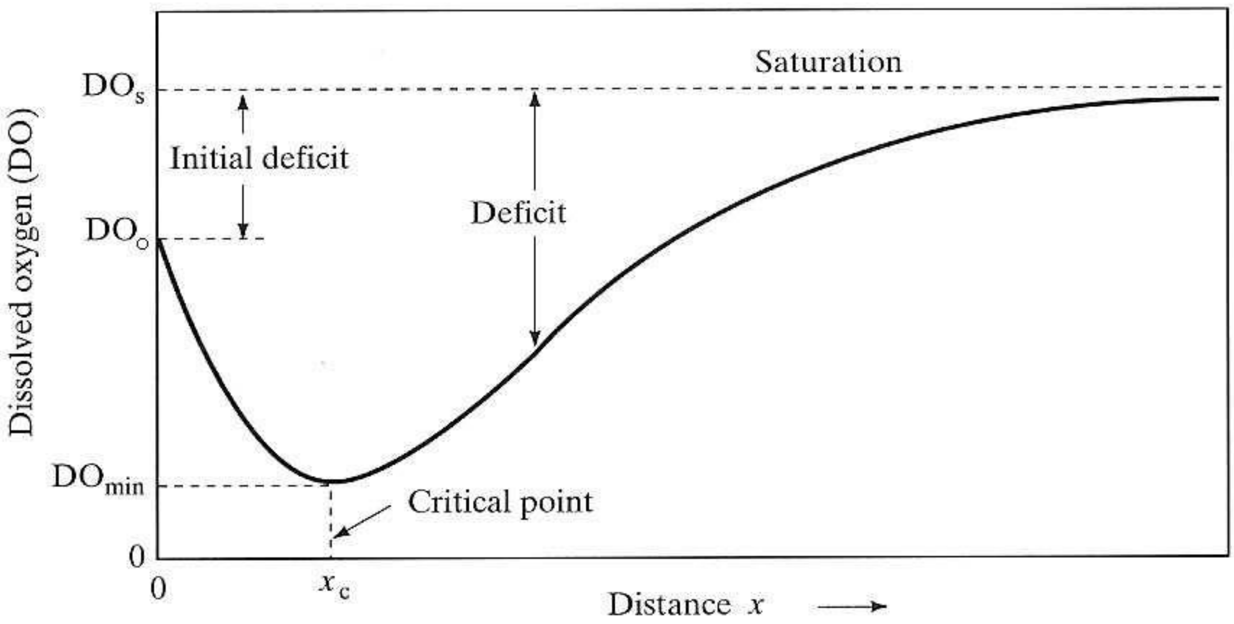


Fig 5: Oxygen Sag Curve

ii. Zone of active decomposition: This zone is marked by heavy pollution. Water is darker and grayish. DO concentration falls down to zero. Evolution of gases like carbon dioxide, methane, hydrogen sulphide etc with masses of sludge forming an ugly scum layer at the surface. As the organic decomposition slackens due to stabilization of organic matter , the reaeration sets in and D.O. again rises to the original level(40% of saturation value).

iii. Zone of recovery: in this zone the river tries to recover from its degraded conditions to its former appearance. The water becomes clearer. Algae reappear while fungi decrease. BOD falls down and DO content rises above 40%of the saturation value.

iv. Zone of cleaner water: the river attains its original conditions with DO rising up to its saturation value. Water becomes very clean in appearance. Usual aquatic life prevails. Some pathogenic organisms may still, however, survive and remain present which confirms to the fact that “once a river water has been polluted it wont be safe to drink it unless it is properly treated”

5. The Streeter-Phelps equation:

It is used as a water quality modeling tool in the study of water pollution. The model describes how decreases in a stream along a certain distance DO by degradation of (BOD). The equation was derived by Streeter and Phelps in 1925, based on field data from the Ohio River. The equation is also known as the DO sag equation

It is a solution to the linear 1st order differential equation that states that the total change in oxygen deficit (D) is equal to the difference between the 2 rates of deoxygenation and reaeration at any time.

$\partial D/\partial t = K_1 L_t - K_2 D$

The Streeter-Phelps equation, assuming a perfectly mixed stream at steady state is then

$$D = \frac{k_1 L_a}{k_2 - k_1}\left(e^{-k_1 t} - e^{-k_2 t}\right) + D_a e^{-k_2 t}$$

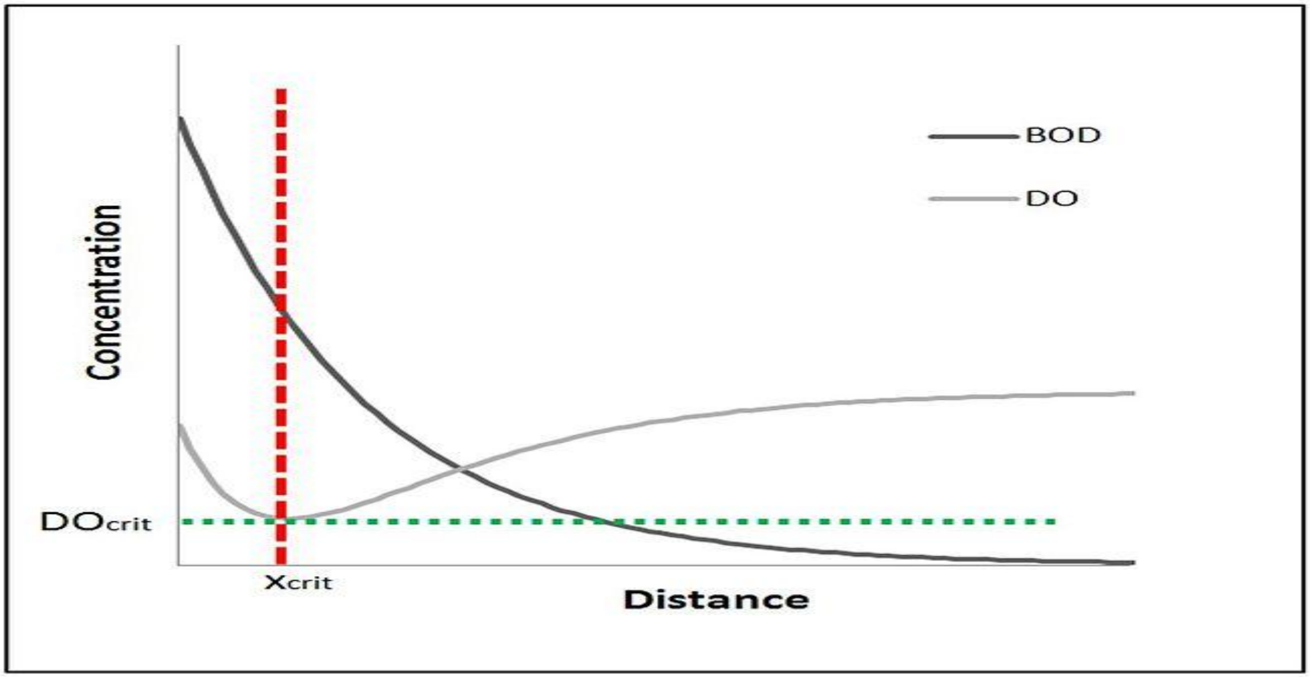
Where,

- D is the saturation deficit, which can be derived from the dissolved oxygen concentration at saturation minus the actual dissolved oxygen concentration.

  $D = DO_{sat} - DO$.

- K_1 is the deoxygenation rate, usually in d^{-1}.
- K_2 is the reaeration rate, usually in d^{-1}.
- L_a is the initial oxygen demand of organic matter in the water, also called BOD (0) (BOD at time t=0). The unit mg/l.
- L_t is the oxygen demand remaining at time t, .$L_t = L_a e^{-k_1 t}$
- D_a is the initial oxygen deficit in mg/l.
- t is the elapsed time, usually.

The Streeter-Phelps equation is also known as the DO sag equation. This is due to the shape of the graph of the DO over time.



Minimum oxygen deficit

On the DO sag curve a minimum concentration occurs at some point, along a stream. If the Streeter-Phelps equation is differentiated with respect to time, and set equal to zero, the time at which the minimum DO occurs is expressed by:

$$t_{crit} = \frac{1}{k_2 - k_1} \ln\left[\frac{k_2}{k_1}\left(1 - \frac{D_a(k_2 - k_1)}{L_a k_1}\right)\right]$$

To find the value of the critical oxygen deficit, D_{crit}, the Streeter-Phelps equation is combined with the equation above, for the critical time, t_{crit}. Then

$$D_{crit} = \frac{k_1}{k_2} e^{(-k_1 - k_2)t_{crit}}$$

and thus the minimum dissolved oxygen concentration is

$$DO_{crit} = DO_{sat} - D_{crit}$$

Mathematically it is possible to get a negative value of DO_{crit}, although it's not possible to have a negative amount of DO in reality.

The distance travelled in a river from a given point source pollution or waste discharge downstream to the DO_{crit} (which is the minimum DO) is found by $x_{crit} = vt_{crit}$, where v is the flow velocity of the stream.

Temperature correction:

Both the deoxygenation rate, k_1 and reaeration rate, k_2 can be temperature corrected, following the general formula.

$$k = k_{20}\theta^{(T-20)}$$

where

- k_{20} is the rate at 20 degrees Celsius.
- **θ** is a constant, which differs for the two rates.
- T is the actual temperature in the stream in degC.

The following data of the two rivers the Mahanadi and Kathajodi were obtained from Orissa State Pollution Control Board for the year 2007, 2008, 2009 & 2010:

PRE (22.11.2007)						
Sl. No.	**Location**	**pH**	**TSS (mg/l)**	**DO (mg/l)**	**BOD (mg/l)**	**COD (mg/l)**
1	Mundali	8.18	20	9.7	1.6	3.5
2	Chahata Ghat	7.19	20	8.9	3.8	14
3	Gadagadia Ghat (U/S)	7.95	36	8.6	1.0	3.5
4	Gadagadia Ghat (D/S)	8.13	12.0	8.5	1.4	7.0
5	Zobra	7.55	16	8.1	2.4	14
6	Kanehipur	7.96	12.0	8.3	1.2	7.0
7	Puri Ghat	7.79	18.0	8.6	1.6	7.0
8	Khan Nagar	8.33	18.0	8.5	1.2	7.0
9	Gopalpur	8.18	28	8.1	1.0	21.1

DURING (24.11.2007)						
Sl. No.	**Location**	**pH**	**TSS (mg/l)**	**DO (mg/l)**	**BOD (mg/l)**	**COD (mg/l)**
1	Mundali	8.07	10.0	9.4	1.04	10.6
2	Chahata Ghat	8.21	8.0	8.4	1.4	7.0
3	Gadagadia Ghat (U/S)	7.78	14.0	8.1	2.2	10.6
4	Gadagadia Ghat (D/S)	8.22	20.0	8.4	1.2	7.0
5	Zobra	8.33	14.0	8.2	1.2	10.6
6	Kanehipur	8.17	6.0	8.6	1.6	10.6
7	Puri Ghat	8.17	16.0	8.5	1.0	14.0
8	Khan Nagar	8.21	14.0	8.4	1.2	7.0
9	Gopalpur	8.28	16.0	8.4	1.4	14.0

POST (06.12.2007)						
Sl. No.	**Location**	**pH**	**TSS (mg/l)**	**DO (mg/l)**	**BOD (mg/l)**	**COD (mg/l)**
1	Mundali	8.21	2	9.4	1.4	3.5
2	Chahata Ghat	8.11	4	9.4	1.4	3.5
3	Gadagadia Ghat (U/S)	8.09	12	9.8	1.2	3.5
4	Gadagadia Ghat (D/S)	7.89	6.0	9.3	1.8	10.6
5	Zobra	8.14	6.0	9.1	1.4	7.0
6	Kanehipur	8.1	6.0	9.3	1.2	3.5
7	Puri Ghat	8.04	6.0	9.3	1.8	7.0
8	Khan Nagar	8.12	6.0	9.1	1.8	7.0
9	Gopalpur	8.11	8.0	8.9	1.6	24.6

PRE (11.11.2008)						
Sl. No.	**Location**	**pH**	**TSS (mg/l)**	**DO (mg/l)**	**BOD (mg/l)**	**COD (mg/l)**
1	Mundali	7.5	8.0	8.2	1.4	6
2	Chahata Ghat	7.2	10.0	8.1	1.6	6
3	Gadagadia Ghat (U/S)	7.2	12.0	8.2	1.8	8
4	Zobra	7.5	10.0	8.1	1.4	6
5	Kanehipur	7.4	10.0	8.3	1.4	6
6	Puri Ghat	7.7	16.0	8.1	1.6	8
7	Khan Nagar	7.3	14.0	8.3	1.6	8
8	Gopalpur	7.7	12.0	8.1	1.6	12

DURING (13.11.2008)						
Sl. No.	**Location**	**pH**	**TSS (mg/l)**	**DO (mg/l)**	**BOD (mg/l)**	**COD (mg/l)**
1	Mundali	7.6	12	7.8	1.4	8
2	Chahata Ghat	7.6	12	7.8	1.8	8
3	Gadagadia Ghat (U/S)	7.6	16	7.6	2.0	12
4	Zobra	7.7	12	7.6	1.4	6
5	Kanehipur	7.5	8	8.1	1.6	8
6	Puri Ghat	7.6	14	7.5	1.8	12
7	Khan Nagar	7.4	12	7.2	1.8	8
8	Gopalpur	7.6	12	8.0	1.6	16

POST (28.11.2008)						
Sl. No.	**Location**	**pH**	**TSS (mg/l)**	**DO (mg/l)**	**BOD (mg/l)**	**COD (mg/l)**
1	Mundali	7.3	6	8.3	1.2	6
2	Chahata Ghat	7.1	6	8.2	1.4	6
3	Gadagadia Ghat	7.3	8	8.1	1.6	8
4	Zobra	7.1	6	8.2	1.4	6
5	Kanehipur	7.2	6	8.2	1.4	6
6	Puri Ghat	7.5	10	8.1	1.6	8
7	Khan Nagar	7.4	6	8.1	1.4	6
8	Gopalpur	7.8	6	8.2	1.4	8

PRE (30.10.2009)						
Sl. No.	**Location**	**pH**	**TSS (mg/l)**	**DO (mg/l)**	**BOD (mg/l)**	**COD (mg/l)**
1	Mundali	7.3	4	8.0	2	4
2	Chahata Ghat	7.2	12	7.6	5	8
3	Gadagadia Ghat	7.1	52	7.4	8	8
4	Zobra	7.3	14	7.8	4	8
5	Kanehipur	7.2	24	8.0	4	12
6	Puri Ghat	7.1	38	7.6	6	12
7	Khan Nagar	7.2	10	7.4	8	16
8	Gopalpur	7.2	14	7.2		16

DURING (02.11.2009)						
Sl. No.	**Location**	**pH**	**TSS (mg/l)**	**DO (mg/l)**	**BOD (mg/l)**	**COD (mg/l)**
1	Mundali	7.2	34	8.0	1.4	4
2	Chahata Ghat	7.2	62	7.6	1.8	12
3	Gadagadia Ghat	7.2	230	6.6	2.2	16
4	Zobra	7.3	26	6.6	1.8	8
5	Kanehipur	7.3	58	7.4	1.6	8
6	Puri Ghat	7.3	74	6.8	1.8	12
7	Khan Nagar	7.1	64	7.4	1.8	12
8	Gopalpur	7.2	94	7.4	1.6	12

POST (24.11.2009)						
Sl. No.	**Location**	**pH**	**TSS (mg/l)**	**DO (mg/l)**	**BOD (mg/l)**	**COD (mg/l)**
1	Mundali	7.2	14	8.4	1.4	4
2	Chahata Ghat	7.3	20	8.0	1.6	4
3	Gadagadia Ghat	7.3	16	7.8	1.6	8
4	Zobra	7.4	22	8.0	1.5	8
5	Kanehipur	7.3	20	7.8	1.5	8
6	Puri Ghat	7.4	16	7.8	1.6	12
7	Khan Nagar	7.3	10	7.4	1.6	8
8	Gopalpur	7.3	10	7.2	13.6	28

PRE (16.11.2010)					
Sl. No.	**Location**	**pH**	**TSS (mg/l)**	**DO (mg/l)**	**BOD (mg/l)**
1	Mundali	7.3	6	7.2	0.8
2	Chahata Ghat	7.3	12	7.0	1.6
3	Gadagadia Ghat	7.2	40	7.8	1.0
4	Zobra	7.3	16	7.8	1.2
5	Kanehipur	7.3	20	8.0	0.8
6	Puri Ghat	7.3	28	7.2	1.0
7	Khan Nagar	7.3	12	7.0	1.0
8	Gopalpur	7.1	24	7.4	1.2

DURING (24.11.2010)					
Sl. No.	**Location**	**pH**	**TSS (mg/l)**	**DO (mg/l)**	**BOD (mg/l)**
1	Mundali	7.3	28	6.4	1.2
2	Chahata Ghat	7.3	68	6.4	1.2
3	Gadagadia Ghat	7.4	250	6.0	2.0
4	Zobra	7.3	30	7.0	1.6
5	Kanehipur	7.5	54	6.4	1.2
6	Puri Ghat	7.5	80	6.4	1.8
7	Khan Nagar	7.4	72	7.2	1.2
8	Gopalpur	7.1	86	6.6	1.6

POST (04.12.2010)					
Sl. No.	**Location**	**pH**	**TSS (mg/l)**	**DO (mg/l)**	**BOD (mg/l)**
1	Mundali	7.3	6	7.6	0.8
2	Chahata Ghat	7.2	10	8.2	0.8
3	Gadagadia Ghat	7.1	46	7.8	0.8
4	Zobra	7.1	14	8.2	2.4
5	Kanehipur	6.9	16	8.4	1.8
6	Puri Ghat	7.1	22	8.0	0.8
7	Khan Nagar	6.9	16	8.0	1.2
8	Gopalpur	7.2	26	7.6	4.2

6. RESULTS AND DISCUSSIONS:

I was asked to design a Streeter-Phelp's model on the Kathajodi and the Mahanadi river with the help of the above data of DO and BOD. I compiled few programs in the software MATLAB and obtained the following results.

The coding of the program is as follows:

Program 1: for determination of the value of Kd between two points Zobra and Kanheipur 7km distance apart.

```
s=7000;
v=0.2;
t=(s/v)/(24*3600);
Lt=1.2;
 L=0.8;
Kd=-(1/t)*log10(Lt/L);
```

And **Program2:** to find out the value of Dt beween two stations namely Mundali and Purighat :

```
s=8000;
v=0.2;
t=(s/v)/(24*3600);
Kr=1;
Kd=0.25;
D0=2.57;
q1=power(-(Kd*t),10)-power(-(Kr*t),10);
q2=D0*power(-(Kr*t),10);
Dt=(((Kd*L)/(Kr-Kd))*q1) +q2
```

Similar programs were run for other stations by varying the value of "s", the distance between two stations.

From the data of the year 2010 results of the Kathajodi river, considering the two stations Mundali and Purighat along the Kathajodi river, value of BOD changes from 0.8 to 1.0mg/l. Distance between the two stations 8km. Assuming the stream velocity as 0.2m/s MATLAB program was executed. The result obtained was as given below. Deoxygenation rate constant k value is found to be negative as value of BOD is increasing along downstream, indicating discharge of sewage water into the river at some location(s) in between the two stations causing pollution in the river water.

```
>> s=8000;
v=0.2;
t=(s/v)/(24*3600)
Lt=1;
L=0.8;
Kd=-(1/t)*log(Lt/L)

t =

    0.4630


Kd =

   -0.4820

>>
```

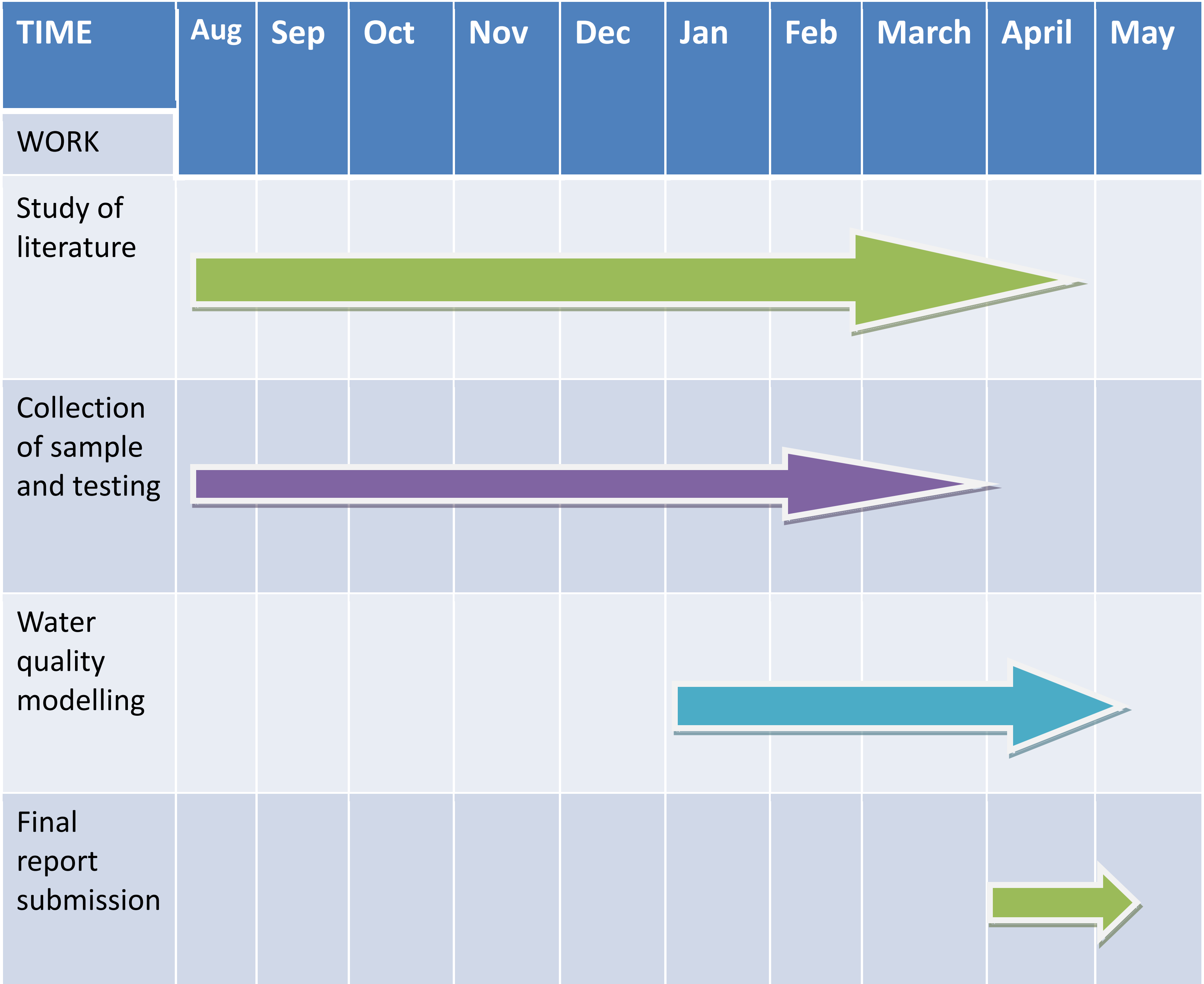
```
>> s=8000;
v=0.2;
t=(s/v)/(24*3600)
L=0.8;
Kd=0.25;
Lt=L*(exp(-(Kd*t)))

t =

    0.4630


Lt =

    0.7126

>>
```

```
>> v=0.2;
 s=4000;t=(s/v)/(24*3600)
L=1;
Kd=0.25;Kr=1;
DO=0.43;
q1=(exp(-(Kd*t)))-(exp(-(Kr*t)));
q2=DO*exp(-(Kr*t));
Dt=(((Kd*L)/(Kr-Kd))*q1)  +q2

t =

    0.2315


Dt =

    0.3913

>>
```

```
>> s=7000;
v=0.2;
t=(s/v)/(24*3600)
Lt=1.6;
L=2;
Kd=-(1/t)*log(Lt/L)

t =

    0.4051


Kd =

    0.5508

>>
```

```
>> s=8000;
v=0.2;
t=(s/v)/(24*3600)
Lt=1.2;
L=1.6;
Kd=-(1/t)*log(Lt/L)

t =

    0.4630


Kd =

    0.6214

>>
```

From the data obtained from the Orissa State Pollution Control Board,during 24.11.2010 along the Mahanadi river along the downstream the BOD decreased from the sample stations Gadgadia Ghat to Zobra and then from Zobra to Kanheipur. Here the model fits in as BOD is decreasing along the downstream direction. So value of deoxygenation rate constant is coming positive and within an allowable range.



7. TIME LINE OF THE PROJECT

8. Conclusion:

From the literature study carried out it was observed that high level of sewage related pollutants are present in the groundwater of the area near the main sewerage.

Most of the near-drain wells exhibited high concentration of Cl^-, NH_4^+, NO_3^- , SO_4^{2-} , PO_4^{3-} indicating continuous influence of the sewerage was the source of pollution.

The wells within 20m range of the sewerage should be avoided until tested as these wells contain high value of pollutants.

In the absence of any major industry and agricultural field in the area the main source of pollutants of surface water in Cuttack is the residential areas that produce both inorganic and organic wastes that discharge the untreated waste into river. At the sewage discharge points in the Kathajodi at Khannagar and Mattagajapur maximum pollution was recorded. The Kathajodi was found to be most polluted followed by the Taladanda canal and then the Mahanadi.

Contamination of the Kathajodi continues till the last stretches of the study area.

The rivers are highly polluted in summer season followed by winter and rainy season. During summer lower water volume and accelerated growth of microbes in the high temperature results in depletion of DO thus making the water most polluted.

Situation in the Kathajodi can become alarming to the inhabitants in the study area if the sewage water isn't treated before discharging into the river.

Sewage should be treated before discharging into the rivers and emphasis should be given on proper repair of the sewerage drain to prevent any further contamination of the subsurface environment.

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